

APPENDIX D

BMP NUTRIENT REDUCTION CALCULATIONS

Calculating the Required Total Maximum Daily Load Reductions Based on Land-use

The Total Maximum Daily Load (TMDL) for receiving waters in the Appoquinimink calls for a 60% reduction in total nitrogen (TN) and total phosphorus (TP) (EPA, 2003). The baseline period for this TMDL was established from 1992 land use data used to determine the acreages of each of the following land uses: Urban, Agricultural, Forest, Wetland, Water, and Other, which includes land uses like rangeland and barren land. The results are tabulated below (Table 1).

Table 1. 1992 Appoquinimink Watershed Land-use Acreages						
Urban	Agricultural	Forest	Wetland	Water	Other	Total acreage
3,156	18,556	2,677	3,769	1,117	389	29,664

In order to calculate nutrient loads from non-point pollution sources, the land use acreages from Table 1 were combined with the land use loading rates in Table 2, which were determined based on results of research conducted by experts in the Appoquinimink Watershed to produce daily nutrient loads according to land use, as displayed in Table 3.

Table 2. Land-use Loading Rates			
	TN (lbs/acre/yr)	TP (lbs/acre/yr)	Source
Developed	15.0	0.48	Ritter and Levan (1992) average of high and low density
Agriculture	25.0	0.60	Ritter and Levan (1992)
Grasslands	10.0	0.40	Ritter and Levan (1992)
Forests	5.0	0.25	Ritter and Levan (1992)
Wetlands	0.0	0.00	Ritter and Levan (1992)
Water	12.0	0.75	Ritter and Levan (1992)
Other	10.0	0.40	Ritter and Levan (1992)

Table 3. 1992 Appoquinimink Watershed Land-use Based Loads

	Urban	Agricultural	Forest	Wetland	Water	Other	Total
TN (lbs/day)	129.70	1,270.96	36.67	0.00	36.72	10.66	1,484.71
TP (lbs/day)	4.11	30.50	1.83	0.00	2.30	0.43	39.17

I. Baseline load calculation for land-use type by reduction area:

Using the land use loading rates listed in Table 2, the nutrient loads coming from non-point sources during the baseline period are determined using the equation below. It should be noted that the grassland loading rate was used to determine the loads from the "Other" land use category.

$$\begin{array}{|c|} \hline \text{Nutrient load} \\ \text{lbs/yr \& lbs/day} \\ \text{(Table 3)} \\ \hline \end{array} = \begin{array}{|c|} \hline \text{Acreage of} \\ \text{specific land-} \\ \text{use (Table 1)} \\ \hline \end{array} \times \begin{array}{|c|} \hline \text{Loading rate for specific} \\ \text{land-use (lbs/acre/yr)} \\ \text{(Table 2)} \\ \hline \end{array}$$

EX: TN load for urban land use:

$$\begin{array}{|c|} \hline \text{TN load} \\ \hline \end{array} = \begin{array}{|c|} \hline 3,156 \text{ acres} \\ \hline \end{array} \times \begin{array}{|c|} \hline 15 \text{ lbs} \\ \text{TN/acre/yr} \\ \hline \end{array} = \begin{array}{|c|} \hline 47,340 \text{ lbs TN/yr} \\ \text{or} \\ 129.70 \text{ lbs} \\ \text{TN/day} \\ \hline \end{array}$$

II. Required TMDL reduction on a land-use basis:

The annual and daily nutrient load reductions needed from non-point sources to achieve the reductions outlined in the TMDL are calculated using the following equation. For the Appoquinimink Watershed, the TN load needs to be reduced by 890.83 lbs/day and the TP load by 23.50 lbs/day. In order to achieve these reductions, the best management practices (BMPs) discussed in the Pollution Control Strategy must be implemented.

$$\begin{array}{|c|} \hline \text{Required TMDL} \\ \text{reduction} \\ \text{(lb/day)} \\ \hline \end{array} = \begin{array}{|c|} \hline \text{Baseline load} \\ \text{(lb/day)} \\ \hline \end{array} \times \begin{array}{|c|} \hline \text{Percent} \\ \text{reduction} \\ \hline \end{array}$$

EX: TN TMDL required load reduction:

$$\begin{array}{|c|} \hline \text{Required TMDL} \\ \text{reduction (lb/day)} \\ \hline \end{array} = \begin{array}{|c|} \hline 1,484.71 \text{ lbs} \\ \text{TN/day} \\ \hline \end{array} \times \begin{array}{|c|} \hline 60\% \\ \hline \end{array} = \begin{array}{|c|} \hline 890.83 \text{ lbs} \\ \text{TN/day} \\ \hline \end{array}$$

Onsite Wastewater Disposal System (OWTDS) BMP Calculations

In order to determine the nutrient loading by OWTDS to groundwater, local watershed data and knowledge has been utilized.

Twelve OWTDS existing near Red Mill Pond in Lewes, Delaware were monitored in 1993 (DNREC, 1994). The average total phosphorus concentration of the effluent from these systems was 15.7 mg/L, while the total kjeldahl nitrogen (TKN) concentration was 58.5 mg/L and the nitrate/nitrite concentration was 0.8 mg/L. The total nitrogen concentration of the average effluent from this study was summed to equal 59.3 mg/L. Conversations with professionals in this industry have suggested that 50.0 mg/L is a more appropriate value of TN concentrations in on-site effluent and this value has been used in subsequent calculations.

Small systems, which are typical individual household systems, have flows less than 2,500 gpd. The average design flow for individual residential OWTDS is 221 gpd.

The nutrient load to the watershed from drain fields can be established by determining the product of the above concentrations and respective flow rates.

Robertson and Hartman (1999) found that 85% of the total phosphorous in the effluent will be retained in the vadose zone or the unsaturated soil above the water table, most of which is within 12 inches of the drain field (Gold and Sims, 2000). Initial calculations presented by the Department, also based on the Red Mill Pond study, assumed that 87% of TP and 52% of TN is assimilated in the soils once the effluent leaves the septic tank.

The final loading rates from OWTDS to groundwater can be determined using the following equations:

Small systems (<2,500 gpd):

$$[\text{Conc. (mg/l)} \times (\text{lb}/453,592 \text{ mg})] \times [(221 \text{ gal/system/day}) \times (3.7854 \text{ l/gal})] \times (1\text{-soil assimilative capacity})$$

Thus, the OWTDS nutrient loading rates to groundwater in the Appoquinimink Watershed are:

- 0.052 lbs TN/system/day and 0.004 lbs TP/system/day for individual small systems less than 2,500 gpd

I. Connecting OWTDS to Sewer Districts

Since 1992, 11 OWTDS (septic) systems are reported to have been removed from the Appoquinimink watershed by connecting homes and businesses to sewer districts ((New Castle County Special Services, written communication, 2009) and (Town of Middletown, written communication, 2009)). These systems have been connected to sewer districts that dispose of their waste at spray irrigation facilities.

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Reductions for systems that are connected to plants that use spray irrigation receive a 90% efficiency since nutrients remain in the ecosystem (DNREC Groundwater Discharges Section, personal communication, 2003). The nutrient load reductions are calculated using the following equation.

$$\begin{array}{|c|} \hline \text{Nutrient load} \\ \text{reduction} \\ \text{(lbs/day)} \\ \hline \end{array} = \begin{array}{|c|} \hline \text{OWTDS loading} \\ \text{rate} \\ \text{(lbs/system/day)} \\ \hline \end{array} \times \begin{array}{|c|} \hline \text{\# of} \\ \text{eliminated} \\ \text{OWTDS} \\ \hline \end{array} \times \begin{array}{|c|} \hline \text{Reduction} \\ \text{efficiency} \\ \hline \end{array}$$

EX: TN reduction due to OWTDS connection:

$$\begin{array}{|c|} \hline \text{TN load} \\ \text{reduction} \\ \text{(lbs/day)} \\ \hline \end{array} = \begin{array}{|c|} \hline 0.052 \text{ lbs} \\ \text{TN/system/} \\ \text{day} \\ \hline \end{array} \times \begin{array}{|c|} \hline 11 \text{ eliminated} \\ \text{OWTDS} \\ \hline \end{array} \times \begin{array}{|c|} \hline 90\% \\ \hline \end{array} = \begin{array}{|c|} \hline \text{0.52 lbs} \\ \text{TN/day} \\ \hline \end{array}$$

II. Holding Tank Inspection and Compliance Program

On average, holding tanks have a 2,800 gallon capacity. Metcalf and Eddy (1991) reported that holding tanks typically hold 2,596 gallons of effluent and 204 gallons of septage (solids). Recent observations from the compliance program indicate volumes of 2,464 gallons of effluent and 336 gallons of septage volume. The average effluent concentrations previously discussed (50.0 mg TN/L and 15.7 mg TP/L) have been used to determine the effluent loads from holding tanks. The nutrient load contribution from septage in holding tanks will be determined using the nutrient concentrations in septage from holding tanks (600 mg TN/L and 250 mg TP/L), as reported in Wastewater Engineering, Third Edition (Metcalf and Eddy, 1991). The nutrients removed per holding tank pump-out are shown in Table 5, calculated using the above concentrations.

Table 5. Nutrient Reductions from a Holding Tank Pump-Out		
	Total N (lbs/tank/pump-out)	Total P (lbs/tank/pump-out)
Holding Tank Effluent	1.03	0.32
Holding Tank Septage	1.68	0.70
Total	2.71	1.02
<u>Effluent:</u> <i>Nutrients Removed (lbs/tank/pump-out) =</i> <i>Conc. (mg/L) x (lb/453,592 mg) x (2,464 gal/tank) x (3.7854 l/gal)</i>		
<u>Septage:</u> <i>Nutrients Removed (lbs/tank/pump-out) =</i> <i>Conc. (mg/L) x (lb/453,592 mg) x (336 gal/tank) x (3.7854 l/gal)</i>		

There is 1 holding tank currently in the Appoquinimink Watershed. Each time a holding tank is pumped, 2.71 lbs TN and 1.02 lbs of TP do not enter the Appoquinimink.

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Initially, the Department assumed that tanks are pumped-out 16 times per year. The Small Systems Branch, Groundwater Discharges Section of the Division of Water Resources determined this number to be high. Records from the Holding Tank Compliance program indicate that on average, holding tanks are pumped-out about 12 times per year, or once a month (DNREC Groundwater Discharges Section, personal communication, 2001). Thus, this latter figure was used for subsequent calculations to determine the annual load reduction using the equation below.

$$\begin{array}{|c|} \hline \text{Nutrient load} \\ \text{reduction} \\ \text{(lbs/yr)} \\ \hline \end{array} = \begin{array}{|c|} \hline \text{Reduction rate} \\ \text{(lbs/tank/pump-} \\ \text{out)} \\ \hline \end{array} \times \begin{array}{|c|} \hline \frac{12 \text{ pump-outs}}{\text{year}} \\ \hline \end{array} \times \begin{array}{|c|} \hline \text{\# of tanks} \\ \hline \end{array}$$

EX: TN reduction due to Holding Tank Pump Out:

$$\begin{array}{|c|} \hline \text{TN load} \\ \text{reduction} \\ \text{(lbs/yr)} \\ \hline \end{array} = \begin{array}{|c|} \hline 2.71 \text{ lbs} \\ \text{TN/tank/pump} \\ \text{-out} \\ \hline \end{array} \times \begin{array}{|c|} \hline \frac{12 \text{ pump-outs}}{\text{year}} \\ \hline \end{array} \times \begin{array}{|c|} \hline 1 \text{ tank} \\ \hline \end{array} = \begin{array}{|c|} \hline 32.52 \text{ lbs TN/yr} \\ \text{or} \\ 0.09 \text{ lbs TN/day} \\ \hline \end{array}$$

III. OWTDS Pump-outs

Using a GIS, an analysis was conducted that determined as of March 2009, there were 1,436 OWTDS in the Appoquinimink Watershed.

Waste haulers usually deliver waste to the nearest wastewater treatment plant. According to information from the Wilmington Treatment Facility, 53 tanks were pumped from the Appoquinimink Watershed in 2001. In addition, it was estimated that 47 tanks from the Appoquinimink Watershed were pumped from the Kent County Treatment Facility in 2001 because they could not give exact information on the number of systems pumped. This equals 100 tanks being pumped out a year in the Appoquinimink Watershed based on a 1,000 gallon tank capacity. By assuming that after three years, a septic tank will contain 750 gallons of effluent and 250 gallons of septage (volumes based on local inspector-hauler observations), and using the concentrations of effluent and septage given above, the effluent load reductions per system achieved by a pump-out program are shown below in Table 6.

Table 6. Nutrient Reductions from an OWTDS Pump-Out		
	Total N (lbs/system/pump-out)	Total P (lbs/system/pump-out)
OWTDS Effluent	0.31	0.10
OWTDS Septage	1.25	0.52
Total	1.56	0.62
<u>Effluent:</u> <i>Nutrients Removed (lbs/system/pump-out) =</i> <i>Conc. (mg/l) x (lb/453,592 mg) x (750 gal/system) x (3.7854 l/gal)</i>		
<u>Septage:</u> <i>Nutrients Removed (lbs/system/pump-out) =</i> <i>Conc. (mg/l) x (lb/453,592 mg) x (250 gal/system) x (3.7854 l/gal)</i>		

The load reduction in the water column achieved by this practice can be calculated using the following equation.

$$\begin{array}{c}
 \boxed{\text{Nutrient load reduction (lbs/yr)}} = \boxed{\text{Reduction rate (lbs/system/pump-out)}} \times \left[\boxed{\text{\# of existing OWTDS}} \times \boxed{\frac{1 \text{ pump-out}}{3 \text{ years}}} - \boxed{\text{\# of compliant OWTDS}} \right]
 \end{array}$$

EX: TN reduction due to OWTDS pump-out program:

$$\begin{array}{c}
 \boxed{\text{TN load reduction (lbs/yr)}} = \boxed{1.56 \text{ lbs TN/system/pump-out}} \times \left[\boxed{1,034 \text{ existing OWTDS}} \times \boxed{\frac{1 \text{ pump-out}}{3 \text{ years}}} - \boxed{100 \text{ compliant OWTDS}} \right] \\
 \\
 = \boxed{381.68 \text{ lbs TN/year or } 1.05 \text{ lbs TN/day}}
 \end{array}$$

IV. OWTDS Performance Standards

Wastewater pretreatment technologies exist to remove nitrogen, phosphorus, or both from wastewater prior to soil dispersal of the effluent. A consultant hired by the Department evaluated the performance efficiencies of these technologies then recommended performance standards for OWTDS in Delaware and several levels of performance efficiencies for nitrogen and phosphorus (The On-Site Wastewater Corporation, draft written communication, 2003).

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A recommendation in the Appoquinimink Pollution Control Strategy surrounding small septic systems requires new and replacement subdivisions in areas outside of sewer districts to be equipped with systems that can reach standards such as “Performance Standard Nitrogen 3” (PSN3) to reduce nutrients. Technologies that can achieve PSN3 will produce a 50% reduction of effluent TN concentration when compared to the TN influent concentration. The nutrient load reduction can be determined using the following equation.

$$\begin{array}{|c|} \hline \text{Nutrient load} \\ \text{reduction} \\ \text{(lbs/day)} \\ \hline \end{array} = \begin{array}{|c|} \hline \text{OWTDS loading} \\ \text{rate} \\ \text{(lbs/system/day)} \\ \hline \end{array} \times \begin{array}{|c|} \hline \text{\# of existing} \\ \text{OWTDS in} \\ \text{program} \\ \hline \end{array} \times \begin{array}{|c|} \hline \text{Reduction} \\ \text{efficiency} \\ \hline \end{array}$$

EX: TN reduction due to upgrading to alternative systems:

$$\begin{array}{|c|} \hline \text{TN load} \\ \text{reduction} \\ \text{(lbs/day)} \\ \hline \end{array} = \begin{array}{|c|} \hline 0.052 \text{ lbs} \\ \text{TN/system/} \\ \text{day} \\ \hline \end{array} \times \begin{array}{|c|} \hline 1,034 \\ \text{OWTDS} \\ \hline \end{array} \times \begin{array}{|c|} \hline 50\% \\ \hline \end{array} = \begin{array}{|c|} \hline \textbf{27.1 lbs} \\ \textbf{TN/day} \\ \hline \end{array}$$

Stormwater BMP Calculations

I. Stormwater BMPs

Several types of structures that treat stormwater runoff are used throughout the Appoquinimink Watershed. The efficiencies associated with common stormwater BMPs are listed in Table 7. In order to calculate the load reduction to the receiving water body, the calculation outlined below is used. The nitrogen urban loading rate is 15 lbs/acre/yr, while the phosphorus loading rate is 0.5 lb/acre/yr (Ritter and Levan, 1992).

Table 7. Stormwater BMP Reduction Efficiencies (ASCE, 2001)		
BMP	TN (%)	TP (%)
Wet ponds	12	55
Dry pond (extended detention)	15	25
Infiltration (infiltration basin/trench)	65	70
Biofiltration (open channel)*	25	29
Filtering Practice (bioretention)	38	59

*Must be at least 200ft long for TN reduction and 100ft swales are more effective in reducing TP (45%) as compared to 200ft swales (29%).

Nutrient load reduction (lbs/day)	=	Total drainage area treated by structures (acres)	x	Urban loading rate (lbs/acre/yr)	x	Reduction efficiency
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EX: TN reduction due to wet ponds:

TN load reduction (lbs/day)	=	5,861.43 acres treated on average	x	15 lbs TN/acre/yr	x	12%	=	10,550.57 lbs TN/yr or 28.91 lbs TN/day
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II. Potential Future Stormwater Retrofit Projects:

It is anticipated that an additional 3,156 acres of urban area in the Appoquinimink watershed will be retrofitted in the future. It is difficult to project, however, the exact number and type of treatment structures that will be used. The majority of stormwater practices currently in use in the watershed are wet and dry ponds, while infiltration, biofiltration, and filtration structures together are less likely to be used. It is unlikely that these same proportions will be used in future retrofit projects since the construction of ponds will require a considerable amount of space and it may be unfeasible to create these structures in areas that are already developed. Because of this, it has been assumed that future retrofits will be more equitable with equal implementation of ponds and other practices.

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The load reductions achieved from the stormwater BMPs currently on the ground have been summed into two categories, “Ponds” and “Other.” These values were divided by the total area treated in each category to calculate nutrient reduction rates. For “Ponds,” the reduction rates are 1.84 lbs TN/acre/yr and 0.25 lbs TP acre/yr, while the reduction rates for “Other” are 5.69 lbs TN/acre/yr and 0.20 lbs TP acre/yr.

The potential future loading reduction to the stream as a result of retrofitting 3,156 acres of urban lands can thus be determined using the equation below.

$$\begin{array}{|c|} \hline \text{Nutrient load} \\ \text{reduction} \\ \text{(lbs/day)} \\ \hline \end{array} = \begin{array}{|c|} \hline \text{Reduction} \\ \text{rate} \\ \text{(lbs/acre/yr)} \\ \hline \end{array} \times \begin{array}{|c|} \hline \text{Acres of} \\ \text{retrofit} \\ \hline \end{array} \times \begin{array}{|c|} \hline \text{Future} \\ \text{percent use of} \\ \text{practice} \\ \hline \end{array}$$

EX: TN reduction from future stormwater ponds:

$$\begin{array}{|c|} \hline \text{TN load} \\ \text{reduction} \\ \text{(lbs/day)} \\ \hline \end{array} = \begin{array}{|c|} \hline 1.84 \text{ lbs} \\ \text{TN/acre/yr} \\ \hline \end{array} \times \begin{array}{|c|} \hline 3,156 \text{ acres} \\ \hline \end{array} \times \begin{array}{|c|} \hline 50\% \\ \hline \end{array} = \begin{array}{|c|} \hline 2,904 \text{ lbs TN/yr} \\ \text{or} \\ 7.95 \text{ lbs TN/day} \\ \hline \end{array}$$

Open Space Calculations

I. Grassed Open Space

Grassed open space is treated as a land use change from agricultural cropland to grassed open space. Thus, the acres that undergo change will receive a lower loading rate. The loading reduction is calculated as follows.

$$\text{Nutrient load reduction (lb/yr)} = \left[\text{Agricultural loading rate (lbs/acre/yr)} - \text{Grass loading rate (lbs/acre/yr)} \right] \times \text{Acres of open space practices}$$

EX: TN reduction due to open space provisions in the UDC:

$$\text{TN load reduction (lb/yr)} = \left[25 \text{ lbs TN/acre/yr} - 10 \text{ lbs TN/acre/yr} \right] \times 665 \text{ acres} = 9,975 \text{ lbs TN/yr or } 27.33 \text{ lbs TN/day}$$

II. Riparian Buffer

It is assumed that for every one acre of land where riparian buffers are employed, that two upland urban acres are treated. This approach is similar to the practice employed by the Chesapeake Bay Program (CBP, 1998). The efficiencies for nutrient load reductions are an average of the range presented by J.T. Sims and J.L. Campagnini (written communication, 2002). Thus, the agreed efficiencies are as follows:

Forested buffers: TN-- 62% and TP-- 62%

For these BMPs, the actual acre of the practice will be treated as a land use conversion and the reduction efficiencies will be applied to two acres of affected upland for each acre of practice.

$$\text{Nutrient load reduction (lb/yr)} = \left[\left[\text{Agricultural loading rate (lbs/acre/yr)} - \text{Forest loading rate (lbs/acre/yr)} \right] \times \text{Acres of buffers} \right] + \left[2 \times \text{Acres of buffers} \times \text{Urban loading rate (lbs/acre/yr)} \times \text{Reduction efficiency (\%)} \right]$$

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EX: TN reduction due to UDC riparian buffer requirements:

$$\begin{array}{c} \boxed{\text{TN load reduction (lb/yr)}} = \\ \left[\left(\boxed{25 \text{ lbs TN/acre/yr}} - \boxed{5 \text{ lbs TN/acre/yr}} \right) \times \boxed{1,972 \text{ Acres}} + \left(\boxed{2 \times 1,972 \text{ Acres}} \times \boxed{15 \text{ lbs TN/acre/yr}} \times \boxed{62\%} \right) \right] \\ \boxed{76,119.20 \text{ lbs TN/yr or } 208.55 \text{ lbs TN/day}} \end{array}$$

Agriculture BMP Calculations

The following calculations are provided as a result of the Agricultural Pollution Control Strategy Workgroup's efforts in gathering the best available science for nonpoint source pollution prevention from agricultural sources. The workgroup began meeting in April 2002 to gather the best available data on nutrient efficiencies for various agricultural best management practices. These recommendations and calculations are based on averages over several years from different studies and are dependent on weather conditions, soil type, crop production intensity, excess manure generation, topography and other site specific conditions. In addition, a lag time likely exists between practice implementation and benefit observation, which can not currently be estimated since all nutrient fate and transport processes are not well understood at this time.

I. Cover Crops

Nitrogen reduction efficiencies for cover crops were calculated using a weighted average method for each year. The data used in this calculation came from ranges of cover crop TN efficiencies for several plant species presented by J.T Sims and J.L. Campagnini (written communication, 2002). The Workgroup chose a single efficiency, often an average of the range, for the commonly used species in Delaware (Table 8). The United States Department of Agriculture, National Resource Conservation Service provided information on each cover crop planted in the 2008-2009 season in the Appoquinimink Watershed (shown in bold). This information was used to calculate a weighted average efficiency of the crops planted, determined to be 54.9% for the 2008-2009 season. It should be noted that with this approach, the efficiency will change from year to year, depending on the acreage of each cover crop species planted. For TP, the Workgroup referred to the best professional judgment presented by Sims and Campagnini, which was "less than 5%," and will be considered for these purposes as 4.9%. The nutrient load reduction is calculated with the equation shown below.

Table 8. Cover Crop Efficiencies for TN	
Cover Crop Species	Work Group BMP Efficiency (%)
Barley	70
Hairy Vetch	6
Annual Rye	65
Cereal Rye	54.5
Oats	55
Wheat	55

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$$\begin{array}{|c|} \hline \text{Nutrient load} \\ \text{reduction} \\ \text{(lbs/yr)} \\ \hline \end{array} = \begin{array}{|c|} \hline \text{Agricultural} \\ \text{loading rate} \\ \text{(lbs/acre/yr)} \\ \hline \end{array} \times \begin{array}{|c|} \hline \text{Acres of cover} \\ \text{crops} \\ \hline \end{array} \times \begin{array}{|c|} \hline \text{Reduction} \\ \text{efficiency} \\ \text{(\%)} \\ \hline \end{array}$$

EX: TN reduction due to 3,144.80 acres of cover crops:

$$\begin{array}{|c|} \hline \text{TN Load} \\ \text{Reduction} \\ \text{(lbs/day)} \\ \hline \end{array} = \begin{array}{|c|} \hline 25 \text{ lbs} \\ \text{TN/acre/yr} \\ \hline \end{array} \times \begin{array}{|c|} \hline 3,144.80 \\ \text{acres} \\ \hline \end{array} \times \begin{array}{|c|} \hline 54.9\% \\ \hline \end{array} = \begin{array}{|c|} \hline 43,162 \text{ lbs TN/yr} \\ \text{or} \\ 118.25 \text{ lbs} \\ \text{TN/day} \\ \hline \end{array}$$

II. Ponds, Grassed Waterways, Grassed Filter Strips, Wildlife Habitat

The Conservation Reserve Program (CRP) practices are treated as a land use change from agricultural cropland to grassed waterways or grassed filter strips, or wildlife habitat. Thus, the acres that undergo change will receive a lower loading rate. Since the Conservation Reserve Enhancement Program (CREP) was implemented, any new grass filter strips created will be treated as a CREP practice and will receive a reduction calculated by the method described later. The loading reduction is calculated as follows.

$$\begin{array}{|c|} \hline \text{Nutrient load} \\ \text{reduction} \\ \text{(lb/yr)} \\ \hline \end{array} = \left[\begin{array}{|c|} \hline \text{Agricultural} \\ \text{loading rate} \\ \text{(lbs/acre/yr)} \\ \hline \end{array} - \begin{array}{|c|} \hline \text{Grass loading} \\ \text{rate} \\ \text{(lbs/acre/yr)} \\ \hline \end{array} \right] \times \begin{array}{|c|} \hline \text{Acres of CRP} \\ \text{practices} \\ \hline \end{array}$$

EX: TN reduction due to 1,413.80 acres of wildlife habitat:

$$\begin{array}{|c|} \hline \text{TN load} \\ \text{reduction} \\ \text{(lb/yr)} \\ \hline \end{array} = \left[\begin{array}{|c|} \hline 25 \text{ lbs} \\ \text{TN/acre/yr} \\ \hline \end{array} - \begin{array}{|c|} \hline 10 \text{ lbs} \\ \text{TN/acre/yr} \\ \hline \end{array} \right] \times \begin{array}{|c|} \hline 1,413.80 \\ \text{acres} \\ \hline \end{array} = \begin{array}{|c|} \hline 21,207 \text{ lbs TN/yr} \\ \text{or} \\ 58.10 \text{ lbs TN/day} \\ \hline \end{array}$$

III. Filter Strips, Forest Buffers, Riparian Buffers, Wetlands

The Conservation Reserve Enhancement Program (CREP) practices (CP21-grass filter strips) are assumed to act as grassed buffers. CREP practices (CP22-riparian buffer, CP23-wetland restoration and CP3A-hardwood trees) are all assumed to act as forested buffers. The Workgroup assumed that for every one acre of land where these practices are employed, that two upland acres are treated. This approach is similar to the practice employed by the Chesapeake Bay Program (CBP, 1998). The efficiencies for nutrient load reductions are an average of the range presented by J.T. Sims and J.L. Campagnini (written communication, 2002). Thus, the agreed efficiencies are as follows:

Grassed buffers: TN-- 46% and TP-- 54%

Forested buffers: TN-- 62% and TP-- 62%

For these BMPs, the actual acre of the practice will be treated as a land use conversion and the reduction efficiencies will be applied to two acres of affected upland for each acre of practice.

$$\begin{array}{c}
 \boxed{\text{Nutrient load reduction (lb/yr)}} = \\
 \left[\boxed{\text{Agricultural loading rate (lbs/acre/yr)}} - \boxed{\text{Grass/Forest loading rate (lbs/acre/yr)}} \right] \times \boxed{\text{Acres of CREP practices}} + \left[\boxed{2 \times \text{Acres of CREP practices}} \times \boxed{\text{Agricultural loading rate (lbs/acre/yr)}} \times \boxed{\text{Reduction efficiency (\%)}} \right]
 \end{array}$$

EX: TN reduction due to 30.8 acres of CREP filter strips:

$$\begin{array}{c}
 \boxed{\text{TN load reduction (lb/yr)}} = \\
 \left[\boxed{25 \text{ lbs TN/acre/yr}} - \boxed{10 \text{ lbs TN/acre/yr}} \right] \times \boxed{30.8 \text{ Acres}} + \left[\boxed{2 \times 30.8 \text{ Acres}} \times \boxed{25 \text{ lbs TN/acre/yr}} \times \boxed{46\%} \right] \\
 = \boxed{1170.4 \text{ lbs TN/yr or } 3.21 \text{ lbs TN/day}}
 \end{array}$$

IV. Field Border

Nutrient reductions from field borders are treated as Conservation Reserve Program (CRP) practices. These practices are treated as a land use change from agricultural cropland to grassland habitat. Thus, the acres that undergo change will receive a lower loading rate. It is important to note that field borders are measured in feet and must be converted to acres.

$$\text{Nutrient load reduction (lb/yr)} = \left[\text{Agricultural loading rate (lbs/acre/yr)} - \text{Grass loading rate (lbs/acre/yr)} \right] \times \text{Acres of practices}$$

EX: TN reduction due to 18,299 ft of wildlife habitat:

$$\text{TN load reduction (lb/yr)} = \left[\begin{array}{c} 25 \text{ lbs} \\ \text{TN/acre/yr} \end{array} - \begin{array}{c} 10 \text{ lbs} \\ \text{TN/acre/yr} \end{array} \right] \times \begin{array}{c} 8.38 \\ \text{acres} \end{array} = \begin{array}{c} 125.7 \text{ lbs TN/yr} \\ \text{or} \\ 0.35 \text{ lbs TN/day} \end{array}$$

V. Critical Area Planting

Critical area planting is a BMP that controls soil erosion and results in phosphorus reductions since phosphorus adsorbs to soils. The critical area planting practice is considered a hot spot BMP and is applied to areas in fields where soils are severely eroding. Soil loss is based upon NRCS values. The critical area planting practice decreases soil erosion from these highly erodible areas from 10 tons per acre per year to 0.5 tons per acre per year, or a soil loss reduction of 9.5 tons per acre per year. To calculate the reduction from this practice, the acreage of the practice is multiplied by the soil loss reduction value, the amount of readily desorbed phosphorus (0.23 mg P/kg soil) (Sims et al. 1994), and conversion factors.

EX: TP reduction due to 35.80 acres of critical area planting:

$$\text{TP load reduction (lb/yr)} = \text{Acres} \times \text{Reduction in soil loss (9.5 tons/ac/yr)} \times \text{Readily desorbed phosphorus (0.23 mg P/kg Soil)} \times \text{Conversion factors}$$

$$\text{TP load reduction (lb/yr)} = 35.8 \text{ Ac} \times \frac{9.5 \text{ tons}}{\text{Ac} \cdot \text{yr}} \times \frac{0.23 \text{ mg P}}{\text{kg Soil}} \times \frac{2000 \text{ lbs}}{\text{ton}} \times \frac{\text{kg}}{10^6 \text{ mg}} = \begin{array}{c} 0.16 \text{ lb} \\ \text{TP/yr} \\ \text{or} \\ 0.004 \text{ lb} \\ \text{TP/day} \end{array}$$

VI. Conservation Tillage

Conservation tillage is a BMP that controls soil erosion by modifying tillage practices on a farm field which reduces sediment and hence phosphorus losses from the tilled field. Soil loss is again based upon NRCS values. Conservation tillage practice can lower soil erosion to 1.5 tons per acre per year from approximately 4.1 tons per acre per year for conventional tillage, or a soil loss reduction of 2.6 tons per acre per year. To calculate the reduction from this practice, the acreage of the practice is multiplied by the soil loss reduction value, the amount of readily desorbed phosphorus (0.23 mg P/kg soil) (Sims et al. 1994), and conversion factors.

EX: TP reduction due to 4,182.20 acres of conservation tillage:

TP load reduction (lb/yr)	=	Acres	x	Reduction in soil loss (2.6 tons/ac/yr)	x	Readily desorbed phosphorus (0.23 mg P/kg Soil)	x	Conversion factors	
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TP load reduction (lb/yr)	=	4,182.20 Ac	x	$\frac{2.6 \text{ tons}}{\text{Ac} \cdot \text{yr}}$	x	$\frac{0.23 \text{ mg P}}{\text{kg Soil}}$	x	$\frac{2000 \text{ lbs}}{\text{ton}}$	x	$\frac{\text{kg}}{10^6 \text{ mg}}$	=	5 lb TP/yr or 0.01 lb TP/day
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VII. Nutrient Management Plans

To reduce agriculture's impact on water quality, Delaware legislated a nutrient management program in 2002 to oversee nutrient applications within the State. In 2003, 20% of farmers applying nutrients to 10 acres or more or those who manage 8 or more animal units within the state were required by the Nutrient Management Act to create and submit a nutrient management plan (NMP) to the Nutrient Management Commission (NMC). Each year between 2004 and 2007, another 20% of eligible farmers were required to have NMPs, with 100% implementation by January 1, 2007. These plans are routinely updated and modified to meet the nutrient needs of the future cropping rotations and practices.

The Delaware Conservation Partnership (DCP) conducted a survey in July 2007, after the deadline requiring all eligible farm operations to have a plan, to evaluate nutrient management planning in the state. The DCP consists of the Delaware Conservation Districts, the Natural Resources Conservation Service, and the Delaware Department of Natural Resources and Environmental Control, and strives to work together to meet the needs of Delaware Farmers by providing cost-share programs, educational opportunities, and nutrient management planning services. The survey was designed to inform those programs by identifying gaps in information and education and opportunities to spend cost-share dollars more effectively. In short, the purpose of the project was to make nutrient management work better for farmers in Delaware.

The surveys were sent out to everyone who has been certified by the Nutrient Management Program- 2,034 people in all. The Delaware Conservation Partnership

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received 698 responses- about a 34% response rate. The following is the breakdown of responses among different sizes of farms:

1-10 acre farms – 9% response rate
 11-99 acre farms – 29% response rate
 100-499 acre farms – 25% response rate
 500 + acre farms – 20% response rate
 Animal only farms – 10% response rate

Responses varied only slightly among different farm sizes and types, with the exception of whether or not nutrient management provided an economic benefit to their farm. Larger farms and those whose plans were written by a private consultant were most likely to agree that nutrient management provides an economic benefit to their operation. Small farms, animal operations and those whose plan was written by someone on staff were least likely to agree.

The surveys indicated that fertilizer application rates have decreased the most among farmers who till at least 500 acres, while manure applications have decreased most among farmers who till between 11 and 99 acres. When fertilizer application rates are evaluated by county, Sussex farmers reduced the rate of N and P applications the most, Kent reduced N applications the least, whereas New Castle decreased P applications the least.

Table 5. Change in Fertilizer and Manure Application Rates Due to 2002 Nutrient Management Law				
<u>County</u>	<u>Farm Acres</u>	<u>% Change in nitrogen fertilizer applications</u>	<u>% Change in phosphorus fertilizer applications</u>	<u>% Change in manure application</u>
Kent	173,808	13.4	26.9	5.4
New Castle	66,981	16.0	20.1	13.6
Sussex	269,464	18.5	37.1	24.2
Weighted Average		16.7	1.4	19.9

The efficiencies based on the DCP survey can be compared to other estimates of nutrient management planning effectiveness. An Agricultural Workgroup was established to gather the best available science on nonpoint source pollution prevention for agricultural sources. The Workgroup operated off the basic assumption that if fewer nutrients are being applied to the land, fewer nutrients will be lost to Delaware's water bodies. From this premise, the Workgroup determined nutrient efficiencies for various

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agricultural best management practices including the effectiveness of nutrient management planning.

Initially, the Workgroup addressed the impact of nutrient management planning (NMP) in the Inland Bays and Nanticoke watersheds from a study by McGowan and Milliken (1992). This study listed the reductions associated with various management practices observed over a three year period, with a total of 103,736 lbs TN reduced by 2,328 acres under nutrient management planning. To determine a general NMP TN reduction, the Workgroup decided that the reductions and acreage associated with manure allowance and cover crops should be removed from further calculations since reductions for both of these items are determined separately and all NMPs will not include manure relocation. This subtraction gave a total of 1,224 acres of nutrient management planning and a load reduction of 70,136 lbs of TN, resulting in a reduction rate of 57.3 lbs/acre per 3-year planning cycle. McGowan and Milliken (1992) reported that the TN application rate prior to the introduction of NMPs was 280 lbs/acre per 3-year planning cycle, so NMPs produced a 20.5% reduction in TN. This estimate falls in the lower range reported by the State of Maryland (MDNR, 1996), which was 20-39% for nitrogen. The corresponding phosphorus range reported by the Maryland DNR was 9-30%. However, due to the absence of a report similar to the McGowan and Milliken study in Delaware for P, there is not enough information available to determine an appropriate reduction efficiency to apply to NMPs for phosphorus in these two watersheds.

In the Appoquinimink watershed, one representative farm within the watershed volunteered to allow the Workgroup to analyze the nutrient data they routinely gather. This particular farm tracks nutrient application rates to each crop field within a database that goes back to 1999, prior to the passing of the Nutrient Management Act. The data were separated into two groups, pre-Nutrient Management Plans (NMPs) (1999-2002) and post-NMPs (2003-2004), and entered into Statgraphics Software for statistical analysis. It was determined that there was a statistically significant difference between the mean application rates at the 95% confidence level for nitrogen. The average nitrogen application rate decreased by 12.4% from the pre-NMP level and this value will be taken as the NMP reduction efficiency; unfortunately, no reduction could be calculated for phosphorus from this data.

At the request of the NMC, Sims et al. (2008) conducted extensive nutrient mass balance calculations for the State for the years 1996 through 2006. They calculated both input/output and management-oriented mass balances for nitrogen and phosphorus. The Sims et al. (2008) approach included calculations for manure relocation and estimates of biological fixation of nitrogen by leguminous crop and clearly demonstrated that fewer nutrients are being applied to Delaware's cropland.

DNREC Watershed Assessment Section (WAS) has worked with the NMC and the University of Delaware Cooperative Extension to determine the impact of the Nutrient Management Act on the amount of nutrients applied to Delaware's agricultural fields. Using an input-output type analysis using fertilizer sales data and crop yields, WAS

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determined that on a state-wide basis, 47% less nitrogen and 62% less phosphorus has been applied to Delaware's cropland. Both the WAS and Sims et al. (2008) approach produced similar results.

The DCP values, which are based on the reductions in nutrient applications actually reported by Delaware farmers, fall within the range of efficiencies determined by the numerous other methods and data sets discussed above. As a result, DNREC proposes to use the DCP efficiencies to estimate the reduction in nutrient application rates resulting from the promulgation of the Nutrient Management Law.

There were 12,583.65 acres of nutrient management planning in the Appoquinimink Watershed in 2008. Using the TN and TP efficiencies and the agricultural loading rate reported earlier, the annual and daily load reductions due to these acres can be calculated as follows.

TN load reduction (lb/yr)	=	12,583.65 acres under NMPs	X	Agriculture loading rate (25 lbs TN/acre/yr)	X	Reduction efficiency (16%)	=	50,333.5 lbs TN/yr or 137.9 lbs TN/day
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Overall Nutrient Load Reductions

The total nutrient reductions achieved by practices currently on the ground in the wastewater, stormwater, open space and agricultural sectors have been determined. In addition, the nutrient reductions possible from several potential future wastewater management policies and stormwater projects have also been estimated. These values are shown in Table 10 along with the nutrient reductions required to meet the TMDL goals. Current practices have contributed 109% percent of the required TN reduction and 111% percent of the required TP reduction. Potential reductions from the wastewater and stormwater sectors increase the progress for TN to 118% and 126% for TP.

Table 10. Nutrient Reductions Achieved from Current and Potential Future BMPs		
	TN Reduced (lbs/day)	TP Reduced (lbs/day)
Wastewater	1.04	0.24
Stormwater	39.47	7.11
Agriculture	673.49	12.88
Open Space	260.19	5.76
Sub-total	974.19	25.99
Future Wastewater	47.08	1.77
Future Stormwater	32.57	1.96
Total	1,053.83	29.72
Required Reduction	890.83	23.50

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